DIGITAL SYSTEMS

PRINCIPLES AND APPLICATIONS

FOURTH EDITION

Prentice-Hall International Editions

RONALD J. TOCCI

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PREFACE

This book is a comprehensive up-to-date study of the principles and techniques of modern digital systems. It is intended for use in two-year and four-year programs in technology, engineering, and computer science. Although a background in basic electronic devices is helpful, a major portion of the material requires no electronics training. Those portions of the text that utilize electronic concepts can be skipped over without adversely affecting the comprehension of the logic principles.

GENERAL IMPROVEMENTS

This fourth edition contains many general improvements over the previous edition. All the material has been updated to reflect the latest developments in the digital field. A good portion of the material has been rewritten with greater clarity, more extensive illustrations, and additional applications. Each chapter now begins with a list of learning objectives and ends with an extensive glossary of terms that also serves as a chapter summary. A number of section review questions has been added to provide more reinforcement of the text material. A significant number of in-depth end-of-chapter problems has been added, bringing the total to well over 400. Many more illustrative examples have been added so that there are now 200 of them.

In addition to these pedagogical improvements, two major topic areas have been incorporated throughout the text: (1) the new IEEE/ANSI standard for logic symbols, and (2) troubleshooting. The inclusion of the IEEE/ANSI symbols is done gradually, with minimum disruption of the topic flow, and, if desired, the instructor can omit all or part of this material. The extensive troubleshooting coverage is spread over Chapters 4 through 11 and includes presentation of troubleshooting principles and techniques, case studies, 23 troubleshooting examples, and 56 *real* troubleshooting problems (these are printed in blue in the problem sections). When supplemented with proper laboratory exercises, this material should help foster the development of good troubleshooting skills.

SPECIFIC CHANGES

The major topical changes are:

Chapter 2:

Added number systems conversions using an intermediate number system.

Chapter 3:

More timing diagrams; added introduction of IEEE/ANSI symbols.

Chapter 4:

Added introduction of digital IC families and their basic characteristics; new material on common digital IC faults, circuit faults, and troubleshooting techniques.

Chapter 5:

Improved coverage of edge-triggered FFs and transparent latch; added coverage of data lockout FF, Schmitt trigger, astable multivibrators, 555 timer IC; new material on problems caused by clock skew.

Chapter 6:

Improved coverage of 2's-complement representation and hexadecimal arithmetic.

Chapter 8:

Added material on speed–power product, 74AS, 74ALS, 74HC and 74HCT families; increased emphasis on obtaining information from data sheets; introduction of logic pulser and current tracer as troubleshooting tools.

Chapter 9:

New material on digital magnitude comparator; more applications; more on bus signals.

Chapter 10:

Added R/2R ladder, bipolar DACs, and the ADC 0801 A/D converter; more on D/A converter specifications, data acquisition, and digitizing.

Chapter 11:

Added material on PLDs and PLAs, dynamic RAM controllers, sequential memories, FIFOs, CPU–memory interface, troubleshooting RAM systems, and ROM testing; expanded coverage of masked ROM and dynamic RAM.

RETAINED FEATURES

This edition retains all of the features that made the previous editions so widely accepted. It utilizes a block diagram approach to teach the basic logic operations without confusing the reader with the details of internal operation. All but the most basic electrical characteristics of the logic ICs are withheld until the reader has a firm understanding of logic principles. In Chapter 8 the reader is introduced to the internal IC circuitry. At that point, the reader can interpret a logic block's input and output characteristics and "fit" it properly into a complete system.

The treatment of each new topic or device typically follows these steps: the principle of operation is introduced; thoroughly explained examples and applications are presented often using actual ICs; short review questions are posed at the end of the section; and finally, in-depth problems are available at the end of the chapter. Ranging from simple to complex, these problems provide instructors with a wide choice of student assignments. These problems are often intended to reinforce the material without simple repetition of the principles. They require the student to demonstrate comprehension of the principles by applying them to different situations. This also helps the student develop confidence and expand his/her knowledge of the material.

SEQUENCING

It is a rare instructor who uses the chapters of a textbook in the sequence in which they are presented. In fact, I must admit that, for many different reasons, I do not use my own books in that way. This book was written so that, for the most part, each chapter builds on previous material, but it is possible to alter the chapter sequence somewhat. The first part of Chapter 6 (arithmetic operations) can be covered right after Chapter 2 (number systems), although this would produce a long interval before the arithmetic circuits of Chapter 6 are encountered. Much of the material in Chapter 8 (IC characteristics) can be covered earlier (e.g., after Chapter 4 or 5) without causing any serious problems.

This book can be used in either a one-term course or in a two-term sequence. When used in one term, it may be necessary, depending on available class hours, to omit some topics. Here is a list of sections and chapters that can be deleted with minimum disruption. Obviously, the choice of deletions will depend on factors such as program/course objectives and student background.

1. *Chapter 1:* all
2. *Chapter 2:* Sections 6 and 7
3. *Chapter 4:* Sections 7 and 8; Sections 10–13 if troubleshooting is not to be covered
4. *Chapter 5:* Sections 3 and 24
5. *Chapter 6:* Sections 5, 7, 11, 13, 16–18, 20
6. *Chapter 7:* Sections 10, 14–23
7. *Chapter 8:* Sections 9, 17–21
8. *Chapter 9:* Sections 6, 10, 11
9. *Chapter 10:* Sections 6, 13, 14
10. *Chapter 11:* Sections 10, 19–24
11. *Chapter 12:* all

ACKNOWLEDGMENTS

Prior to starting work on this edition, we sent an extensive questionnaire to many users and former users of the third edition. I am grateful to all of those who responded with their comments, critiques, and suggestions. Their input was invaluable as I went through the process of deciding what changes to incorporate in the new edition. I am also very grateful to the people at Prentice-Hall for all of their expertise and professionalism. A special fond thank-you to Alice Barr for her patience and flexibility in dealing with a procrastinating author. She was a constant source of encouragement, and her enthusiasm for the project was, at times, all that kept me going.

Finally, I would like to express my deepest gratitude to my colleague, Frank Ambrosio, who graciously agreed to assist me in preparing this revision. His excellent work on the chapter objectives and glossaries, index, and Instructors' Solutions Manual made it possible for me to meet the publication deadline.

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CONTENTS

1 INTRODUCTORY CONCEPTS

OUTLINE

Upon completion of this chapter, you will be able to:

- Distinguish between analog and digital representations.
- Name the advantages, disadvantages, and major differences among analog, digital, and hybrid systems.
- Understand the need for analog-to-digital converters (ADCs) and digital-to analog converters (DACs).
- Convert between decimal and binary numbers.
- Identify typical digital signals.
- Cite several integrated-circuit fabrication technologies.
- Identify a timing diagram.
- State the differences between parallel and serial transmission.
- Name various memory elements.
- Describe the major parts of a digital computer and understand their functions.

INTRODUCTION

When most of us hear the term "digital," we immediately think of "digital calculator" or "digital computer." This can probably be attributed to the dramatic way that low-cost, powerful calculators and computers have become accessible to the average person. It is important to realize that calculators and computers represent only one of the many applications of digital circuits and principles. Digital circuits are used in electronic products such as video games, microwave ovens, and automobile control systems, and in test equipment such as meters, generators, and oscilloscopes. Digital techniques have also replaced a lot of the older "analog circuits" used in consumer products such as radios, TV sets, and high-fidelity sound recording and playback equipment.

In this book we are going to study the principles and techniques that are common to all digital systems from the simplest on/off switch to the most complex computer. If this book is successful, you should gain a deep understanding of how all digital systems work, and you should be able to apply this understanding to the analysis and troubleshooting of any digital system.

We start by introducing some underlying concepts that are a vital part of digital technology; these concepts will be expanded on as they are needed later in the text. We will also introduce some of the terminology that is so necessary when embarking on a new field of study, and will add to it in every chapter.

1-1 NUMERICAL REPRESENTATIONS

In science, technology, business, and, in fact, in most other fields of endeavor, we are constantly dealing with *quantities*. These quantities are measured, monitored, recorded, manipulated arithmetically, observed, or in some other way utilized in most physical systems. It is important when dealing with various quantities that we be able to represent their values efficiently and accurately. There are basically two ways of representing the numerical value of quantities: *analog* and *digital*.